# 5 Perturbations and Approximation Methods

In this chapter we study methods of approximation frequently used to solve quantum mechanical problems that are too difficult (or impossible) to solve analytically. We will cover both stationary (i.e., time–independent) and time–dependent perturbation techniques involving perturbations of small enough amplitude compared to the unperturbed Hamiltonian of such systems.

Some of the material presented in this chapter is taken from Auletta, Fortunato and Parisi, Chap. 10 and Cohen-Tannoudji, Diu and Laloë, Vol. II, Chaps. XI and XIII.

## 5.1 The Theory of Stationary Perturbations

It is very often the case in quantum mechanics that the Hamiltonian of a system is not explicitly a function of time. These are cases where we need to solve the time-independent form of the Schrödinger equation (see equation (1.56) in Chapter 1). Unfortunately, in most cases it is not possible to solve Schrödinger equation exactly to obtain analytical solutions. Physicists must then resort to methods of approximations in order to develop solutions of increasing accuracy by considering higher orders of perturbations.

We consider the case of a quantum mechanical system with an Hamiltonian such that

$$\hat{H} = \hat{H}_0 + W'', \tag{5.1}$$

where $\hat{H}_0$ is the unperturbed Hamiltonian, for which we know the eigenvectors and eigenvalues, and $W'$ is a perturbation such that $W'' \ll \hat{H}_0$ (but see below). We assume that both $\hat{H}_0$ and $W''$ are independent of time. This lack of dependence on time and the difference in importance between the two components of the Hamiltonian is the basis for the *theory of stationary perturbations*.

Given the relative smallness of the perturbation we normalize it in relation to $\hat{H}_0$ and introduce a real parameter $\lambda \ll 1$ such that

$$\hat{W}'' = \lambda W \tag{5.2}$$

and

$$\hat{H}(\lambda) = \hat{H}_0 + \lambda W. \tag{5.3}$$

We will assume that the unperturbed Hamiltonian $\hat{H}_0$ possesses a set of eigenvectors $\{|u_n^i\rangle\}$, which also forms a basis (i.e., $\langle u_n^i | u_m^j \rangle = \delta_{nm}\delta_{ij}$ and $\sum_{n,i} |u_n^i\rangle\langle u_n^i|$), and

# Perturbations Theory And Methods

**Stephen Wilson**

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diverse that this part of applied mathematics appears as an aggregate of poorly connected methods The majority of these methods require some previous guessing of a structure of the desired asymptotics The Poincare method of normal forms and the Bogolyubov Krylov Mitropolsky averaging methods well known in the literature should be mentioned specifically in connection with what will follow These methods do not assume an immediate search for solutions in some special form but make use of changes of variables close to the identity transformation which bring the initial system to a certain normal form Applicability of these methods is restricted by special forms of the initial systems **Large Order Perturbation Theory and Summation Methods in Quantum Mechanics** Gustavo A. Arteca,Francisco M. Fernandez,Eduardo A. Castro,2012-12-06 The book provides a general broad approach to aspects of perturbation theory The aim has been to cover all topics of interest from construction analysis and summation of perturbation series to applications Emphasis is placed on simple methods as well as clear intuitive ideas stemming from the physics of systems of interest **Perturbation Methods in Applied Mathematics** J. Kevorkian,J.D. Cole,2013-03-09 This book is a revised and updated version including a substantial portion of new material of J D Cole s text Perturbation Methods in Applied Mathe matics Ginn Blaisdell 1968 We present the material at a level which assumes some familiarity with the basics of ordinary and partial differential equations Some of the more advanced ideas are reviewed as needed therefore this book can serve as a text in either an advanced undergraduate course or a graduate level course on the subject The applied mathematician attempting to understand or solve a physical problem very often uses a perturbation procedure In doing this he usually draws on a backlog of experience gained from the solution of similar examples rather than on some general theory of perturbations The aim of this book is to survey these perturbation methods especially in connection with differ ential equations in order to illustrate certain general features common to many examples The basic ideas however are also applicable to integral equations integrodifferential equations and even to difference equations In essence a perturbation procedure consists of constructing the solution for a problem involving a small parameter B either in the differential equation or the boundary conditions or both when the solution for the limiting case B 0 is known The main mathematical tool used is asymptotic expansion with respect to a suitable asymptotic sequence of functions of B Analyzing Multiscale Phenomena Using Singular Perturbation Methods Jane Cronin,Robert E. O'Malley,American Mathematical Society, To understand multiscale phenomena it is essential to employ asymptotic methods to construct approximate solutions and to design effective computational algorithms This volume consists of articles based on the AMS Short Course in Singular Perturbations held at the annual Joint Mathematics Meetings in Baltimore MD Leading experts discussed the following topics which they expand upon in the book boundary layer theory matched expansions multiple scales geometric theory computational techniques and applications in physiology and dynamic metastability Readers will find that this text offers an up to date survey of this important field with numerous references to the current literature both pure and applied **Perturbation Methods with Applications in Science and Engineering**

İlkay Bakırtaş,2018-10-17 The governing equations of mathematical chemical biological mechanical and economical models are often nonlinear and too complex to be solved analytically Perturbation theory provides effective tools for obtaining approximate analytical solutions to a wide variety of such nonlinear problems which may include differential or difference equations In this book we aim to present the recent developments and applications of the perturbation theory for treating problems in applied mathematics physics and engineering The eight chapters cover a variety of topics related to perturbation methods The book is intended to draw attention of researchers and scientist in academia and industry *Perturbation Methods* E. J. Hinch,1991-10-25 In this book the author presents the theory and techniques underlying perturbation methods in a manner that will make the book widely appealing to readers in a broad range of disciplines Methods of algebraic equations asymptotic expansions integrals PDEs strained coordinates and multiple scales are illustrated by copious use of examples drawn from many areas of mathematics and physics The philosophy adopted is that there is no single or best method for such problems but that one may exploit the small parameter given some experience and understanding of similar perturbation problems The author does not look to perturbation methods to give quantitative answers but rather uses them to give a physical understanding of the subtle balances in a complex problem **Introduction to the General Theory of Singular Perturbations** S. A. Lomov, This book is aimed at researchers and students in physics mathematics and engineering It contains the first systematic presentation of a general approach to the integration of singularly perturbed differential equations describing nonuniform transitions such as the occurrence of a boundary layer discontinuities boundary effects and so on The method of regularization of singular perturbations presented here can be applied to the asymptotic integration of systems of ordinary and partial differential equations **Introduction to Perturbation Theory in Quantum Mechanics** Francisco M. Fernandez,2000-09-19 Perturbation theory is a powerful tool for solving a wide variety of problems in applied mathematics a tool particularly useful in quantum mechanics and chemistry Although most books on these subjects include a section offering an overview of perturbation theory few if any take a practical approach that addresses its actual implementation p **Algebraic Analysis of Singular Perturbation Theory** Takahiro Kawai,Yoshitsugu Takei,2005 The topic of this book is the study of singular perturbations of ordinary differential equations i e perturbations that represent solutions as asymptotic series rather than as analytic functions in a perturbation parameter The main method used is the so called WKB Wentzel Kramers Brillouin method originally invented for the study of quantum mechanical systems The authors describe in detail the WKB method and its applications to the study of monodromy problems for Fuchsian differential equations and to the analysis of Painleve functions This volume is suitable for graduate students and researchers interested in differential equations and special functions *Recent Studies inPerturbation Theory* Dimo Uzunov,2017-06-14 The book contains seven chapters written by noted experts and young researchers who present their recent studies of both pure mathematical problems of perturbation theories and application of perturbation methods to the study of the important topic

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**Table of Contents Perturbations Theory And Methods**

1. Understanding the eBook Perturbations Theory And Methods
    - The Rise of Digital Reading Perturbations Theory And Methods
    - Advantages of eBooks Over Traditional Books
2. Identifying Perturbations Theory And Methods
    - Exploring Different Genres
    - Considering Fiction vs. Non-Fiction
    - Determining Your Reading Goals
3. Choosing the Right eBook Platform
    - Popular eBook Platforms
    - Features to Look for in an Perturbations Theory And Methods
    - User-Friendly Interface
4. Exploring eBook Recommendations from Perturbations Theory And Methods

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